 0030-0950/84/0005-0228 $2.00/0

RELATION OF WATER TABLE DEPTH AND SOIL MORPHOLOGY IN TWO CLAY-RICH SOILS OF NORTHWESTERN OHIO[1]

TED M. ZOBECK,[2] Dept. of Agronomy, The Ohio State University, 2021 Coffey Road, Columbus, OH 43210

A. RITCHIE, JR., Ohio Dept. of Natural Resources, Div. of Soil and Water Conservation, Fountain Square, Columbus, OH 43223

ABSTRACT. Water table levels within the upper 165 cm of the soil and precipitation were measured over a three–yr period for two forested soils representative of clay-rich soils common throughout much of northwestern Ohio. The soils included very poorly drained Hoytville taxadjunct (fine, illitic, mesic Typic Haplaquept) and moderately well drained Glynwood (fine, illitic, mesic Aquic Hapludalf). A water table was observed from February to June in the Hoytville taxadjunct and from March to June in the Glynwood. The soils were also sampled and described in order to relate soil properties to observed water table depths. The Hoytville taxadjunct was dominantly gray throughout the subsoil, and the Glynwood had gray coatings only on ped surfaces. The gray soil matrix of the Hoytville taxadjunct formed in horizons where water tables were observed for as little as 1.5 months, and the gray coatings of the Glynwood formed in horizons where water tables were present for an average of only two weeks each year.

OHIO J. SCI. 84 (5): 228-236, 1984

INTRODUCTION

Saturated zones in soils, the upper limit of which is often called the water table, frequently occur at relatively shallow depths. The depth to the water table is a dynamic soil feature and fluctuates with the seasons and varies from year to year in a given season. Water table fluctuations within the upper two m or so are of particular interest to biologists and soil scientists in Ohio because this is the zone of maximum biological activity and soil formation. Knowledge of the depth and duration of saturated zones in soils is essential in fully understanding many biological phenomena and accurately predicting soil response to a wide variety of management practices.

Soil properties, particularly soil color, are often used to predict the depth to saturated zones. Several studies have related

[1]Manuscript received 22 March 1984 and in revised form 8 June 1984 (#84-13).

[2]Present Address: U.S.D.A.-A.R.S., P.O. Box 909, Big Spring, TX 79720

water table depths to soil characteristics by measuring both properties in the field (Schelling 1960, Fritton and Olson 1972, Thorp and Gamble 1972, Bullock et al. 1974, Harlan and Franzmeier 1974, Duncan 1979, Franzmeier et al. 1983, Zobeck and Ritchie 1984). Although several of these studies (Thorp and Gamble 1972, Harlan and Franzmeier 1974, Zobeck and Ritchie 1984) were made in soils representative of the moderately fine-textured till soils common to west and west-central Ohio, little has been reported on the fine and moderately fine-textured, water modified soils of northwestern Ohio. The properties, distribution, management and use of Hoytville, a very extensive soil occupying over 726,000 acres in northwest Ohio, have been summarized by Blevins and Wilding (1968). Many soil properties were described, but data on the depth to water tables was not available at the time. Taylor et al. (1961) described the drainage characteristics of two clay soils, including Hoytville, common in northwestern Ohio. Their study area included tiled and untiled areas in crops or sod, and measurements were made over a four–mo period.

The relationship of annual water table fluctuations to soil properties has not yet been described for the water modified clay-rich soils of northwest Ohio. This study was made in an effort to relate previously unpublished multi-year observed water table depths to soil properties in representative clay-rich soils of northwest Ohio.

METHODS AND MATERIALS

The study area was located in a mature mixed oak woodlot in Portage Twp, Hancock Co., Ohio (SE 1/4, SE1/4, Sec. 4, T. 2 N., R. 10 E.). A wooded site was chosen because it best corresponds to the vegetation under which the soils have developed. Although the study area lies within the Glacial Lake Plain physiographic area (Rapparlie and Urban 1973), the soils are representative of clay-rich soils occurring on lake plains and till plains throughout much of northwestern Ohio (fig. 1). The woodlot was grazed more than 20 yr ago but has never been managed for wood production. The study site is not artificially drained although nearby fields have been drained. Field drains were approximately 40 m away and not considered to have a significant effect on the water table levels measured in this study. The vegetation was identified by Ohio Department of Natu-

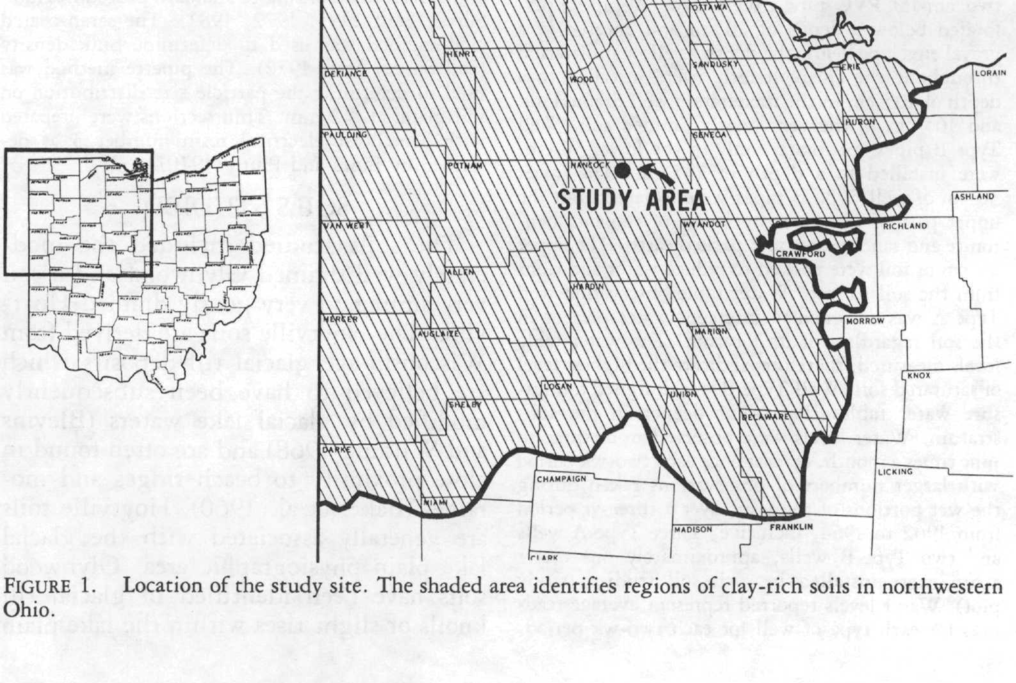

FIGURE 1. Location of the study site. The shaded area identifies regions of clay-rich soils in northwestern Ohio.

ral Resources Service Forester B. H. Mauer. Two different plant communities generally associated with different moisture conditions were identified. The overstory vegetation associated with the very poorly drained soil included (in order of abundance): hickory (*Carya* spp.), basswood (*Tilia americana* L.), northern red oak (*Quercus rubra* L.), ash (*Fraxinus spp.),* bur oak *(Q. macrocarpa* Michx.), chinkapin oak (*Q. Muehlenbergii* Engelm), hawthorn (*Crataegus* spp.), and elm (*Ulmus* spp.). The understory included elm, blue beech (*Carpinus* spp.), sugar maple (*Acer saccharum* Marsh.), northern red oak, hawthorn, white ash (*Fraxinus americana* L.) hickory, basswood, blue beech, and prickly ash (*Zanthoxylum americanum* Mill.). The overstory associated with the moderately well drained soil consisted of northern red oak, white oak (*Q. alba* L.), hickory, bur oak, ash and hawthorn, and the understory included white ash, hawthorn, honey locust (*Gleditsia tricanthos* L.), basswood, elm, prickly ash, white oak and bur oak. The very poorly drained site seemed to correspond to the better drained red oak-basswood subtype of the swamp forest (Gordon 1969). The moderately well drained site generally corresponded to Gordon's oak-hickory forests of the Wisconsin till plain. Determining the precise nature of the plant communities present on each soil was outside the scope of this study.

Two study plots approximately 200 m apart were located on soils with different natural drainage classes, and ground water wells were installed in 1961 by the Ohio Department of Natural Resources, Division of Soil and Water Conservation (formerly the Division of Lands and Soils). Two types of wells were installed (fig. 2). Both types of wells were made of two cm-ID PVC pipe. Well Type A pipes, perforated below a depth of 20 cm and encased in a gravel envelope below the depth to allow infiltration throughout the entire length, were installed to a depth of 105 cm in the moderately well drained soil and 165 cm in the very poorly drained soil. Well Type B pipes, perforated only in the lower 30 cm, were installed to a depth of 165 cm. The lower 30 cm of well Type B pipes were isolated from the upper part of the pipes by layers of cement, bentonite and sand mixes, and packed earth. The upper 25 cm of soil were packed to reduce water additions from the soil surface. Water table observation well Type A was designed to intercept water present in the soil regardless of its location. The water table levels measured, therefore, indicate the highest level of saturated soil. Well Type B was designed to measure water tables that occur deeper in the substratum. Water levels were observed from three to nine times a month, at least once each two-wk period with larger numbers of observations taken during the wet portions of the year, over a three-yr period from 1962 to 1964, inclusive. Three Type A wells and two Type B wells, approximately one meter apart, were installed in each soil studied (study plot). Water levels reported represent average readings for each type of well for each two-wk period.

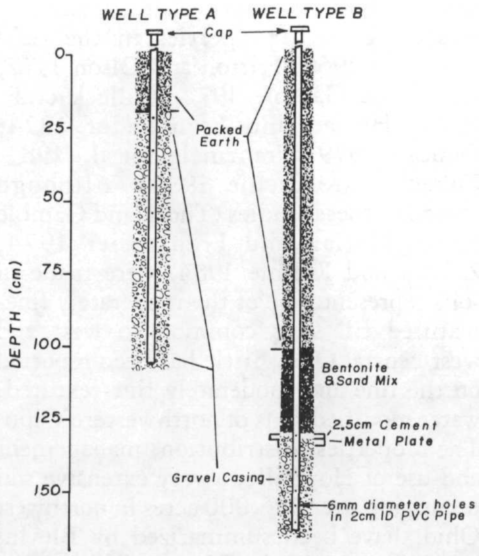

FIGURE 2. Schematic diagram of well types used to observe water table depths.

The pipes were not pumped between measurements. Precipitation was measured with a standard U.S. Weather Bureau recording rain gage in an adjacent clearing approximately 300 m from the study plots. Thorp and Gamble (1972) reported 18% less rainfall occurred under a similar forest cover compared to clearings.

Each plot recently has been excavated, sampled, and described according to standard procedures (Soil Survey Staff 1951, 1972, 1981). The saran-coated clod method was used to determine bulk density (Soil Survey Staff 1972). The pipette method was used to determine the particle size distribution on soil material <2 mm. Thin sections were prepared with Scotchcast electrical resin number 3 as described by Innes and Pluth (1970).

SOILS STUDIED

The soils studied included the moderately well drained Glynwood and a soil very similar to very poorly drained Hoytville. The Hoytville soils are derived from Wisconsin-age glacial till deposits which are believed to have been subsequently modified by glacial lake waters (Blevins and Wilding 1968) and are often found in close proximity to beach ridges and moraines (Baker et al. 1960). Hoytville soils are generally associated with the glacial lake plain physiographic area. Glynwood soils have been identified in glacial till knolls or slight rises within the lake plain and in the northwest Ohio portion of the Wisconsin-age glacial till plain. The soils observed in this study were in close proximity to one another, approximately 200 m apart, and developed under similar climatic conditions, vegetation and parent materials.

Glynwood and Hoytville soils are often found in the same landscape as members of a drainage sequence of soils (hydrosequence) corresponding to landscape position. The typical hydrosequence includes the moderately well drained Glynwood in the higher landscape positions, somewhat poorly drained Nappanee in intermediate positions and very poorly drained Hoytville in depressions and broad flats. In this study, the entire woodlot had a slope of less than one percent and the Glynwood soil was 30 cm higher than the Hoytville soil. Glynwood is classified according to Soil Taxonomy (Soil Survey Staff 1975) as a fine, illitic, mesic Aquic Hapludalf, and the Hoytville is classified as a fine, illitic mesic Mollic Ochraqualf. Laboratory and field analyses (table 1) support the classification of the Glynwood but not the Hoytville. The Hoytville soil did not have an argillic horizon due to a lack of illuvial clay in the subsoil. This observation was supported by observations of soil thin sections. Smeck et al. (1981) also reported a lack of argillic horizon formation in similar very poorly drained soils in western and northwestern Ohio. In addition, the Hoytville surface horizon was too thin to meet the requirements for the Mollic subgroup. The classification of this soil is fine, illitic, mesic Typic Haplaquept. Although the properties of this soil were outside the range of Hoytville, the differences were so small that major interpretations are not

TABLE 1

*Physical and chemical properties for the Hoytville taxadjunct and Glynwood study sites.**

Horizon	Depth cm	Texture	Particle Size Dist. (% <2 mm) Sand	Silt	Clay	Organic Matter %	Moist Matrix Color	Mottle Color	Mottle Type	Surface Coating Color	Surface Coating Type	Primary Structure
						Hoytville						
A	0-10	sicl	16.0	48.4	35.6	9.0	10YR 3/1	7.5YR 4/6	f1d			2fgr
BAg	10-23	sicl	19.8	43.6	36.6	2.6	10YR 4/2	7.5YR 5/6	f1d	10YR 4/2	un	1fpr
Bg1	23-36	sicl	18.5	41.9	39.6	1.7	10YR 4/2	7.5YR 5/6	c1d	10YR 4/2	un	2mpr
Bg2	36-53	sicl	18.9	42.2	38.9	1.0	2.5Y 4/2	7.5YR 5/6	m2p	10YR 4/2	un	1mpr
Bg3	53-84	cl	19.4	44.0	36.7	0.7	2.5Y 4/2	7.5YR 5/6	m2p	10YR 5/3	un	1mpr
BC1	84-107	cl	20.5	43.4	36.1	0.7	10YR 5/6	2.5Y 4/2	m2p	7.5YR 5/2	un	1mpr
BC2	107-130	cl	21.2	41.9	36.9		10YR 5/6	2.5Y 4/2	m1p	10YR 7/2	ca	1mpr
C	130-152	cl	20.5	45.6	33.9		10YR 5/6	2.5Y 4/2	m1p	10YR 7/2	ca	1mpr
						Glynwood						
A	0-10	sil	20.5	58.3	21.2	8.1	10YR 3/2					2mgr
BE	10-20	sil	23.5	54.2	22.3	1.4	10YR 5/3	10YR 5/6	c2d	10YR 5/3	un	1msbk
Bt1	20-33	sic	14.7	40.6	44.7	1.2	10YR 5/6	10YR 5/8	c2f	10YR 5/2	un	2msbk
Bt2	33-48	sic	13.2	40.1	46.7	1.0	10YR 5/6	10YR 5/8	f1f	10YR 5/2	cl	2msbk
Bt3	48-66	sic	18.9	40.3	40.8	1.0	10YR 4/4	10YR 5/6	c2f	10YR 4/2	cl	1fpr
BC	66-79	sicl	19.9	44.0	36.1		10YR 4/4	10YR 5/6	c2f	10YR 5/2	un	1mpr
C1	79-99	cl	21.0	43.8	35.2		10YR 4/4	10YR 5/6	c2f	10YR 7/3	ca	1mpr
C2	99-119	cl	21.1	43.7	35.2		10YR 4/4	10YR 5/6	c2f	10YR 7/1	ca	1mpr
C3	119-130	cl	20.1	44.6	35.3		10YR 4/4	10YR 5/6	c2f	10YR 7/1	ca	1mpl

*Legend: Texture: sicl-silty clay loam; cl-clay loam, sil-silt loam; sic-silty clay;
mottle type: f1d-few, fine, distinct; c1d-common, fine, distince; m2p-many, medium, prominent; m1p-many, fine, prominent; c2d-common, medium, distinct; c2f-common, medium faint; f1f-few, fine faint.
Surface coating: un-unidentifiable; ca-calcium carbonate; cl-clay film;
Primary structure; 2fgr-moderate, fine, granular; 1fpr-weak, fine, prismatic, 2mpr-moderate, medium, prismatic, 1mpr-weak, medium, prismatic 2mgr-moderate, medium, granular; 1msbk-weak, medium, subangular blocky; 2msbk-moderate, medium, subangular block; 1mpl-weak, medium platy.

affected, and the soil will be referred to as a Hoytville taxadjunct (Soil Survey Staff 1980).

RESULTS AND DISCUSSION

WATER TABLE DEPTHS. Comparisons of the depths to the water table observed in Type A and Type B wells, on a given date, were made to determine the relative location and direction of movement of saturated zones in the soil. Water tables are often called "perched" water tables when zones of saturated soil form above zones of unsaturated soil. In many instances, water tables are not perched but continuously saturate the entire profile. The precise locations of all zones of saturation were not measured by the experimental design used in this study. Differences in water table elevations between pipes A and B on a given date do not necessarily show that unsaturated zones occurred between two zones of saturated soil. The differences may be the result of differences in soil permeability and indicate the direction of water movement in the soil. If water is moving downward, the water level in the wells should be highest in the shallow wells and deepest in the deep wells (Franzmeier et al. 1983). Well Type A had the perforated portion in the shallower, more permeable part of the soil than did well Type B.

In this study, the water table depths recorded in both well types for the Hoytville soil were essentially identical for a given observation date (fig. 3), indicating continuous saturation and no water movement. Differences in water table depths between well types on a given observation data were observed for the Glynwood soil.

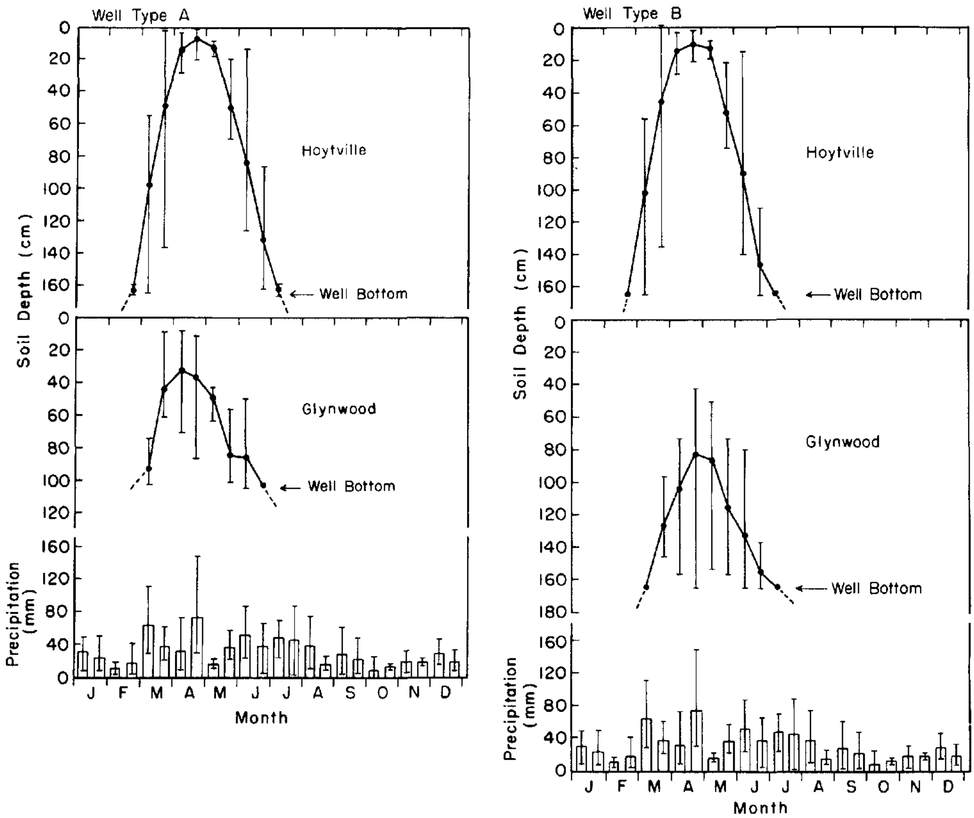

FIGURE 3. Three-yr average water table depths and precipitation by two-wk intervals. The ranges of values over the three-yr study period are indicated by the vertical bars.

The water tables were always higher in the shallower Type A well indicating downward movement of water in the soil.

Higher water table levels in Type A wells, for a given date, also may have reflected more rapid responses to rainfall or snowmelt due to the higher permeability. Since the wells were not pumped out after each measurement and tensiometers were not used to measure soil moisture tension, this possibility was not evaluated.

The study site was located approximately nine km southeast of a long-term weather station located at the Northwest Branch of the Ohio Agricultural Research and Development Center. Comparisons of 26-yr (1956-1982) monthly average precipitation records to the values recorded at the study site during the three-yr study period (table 2) indicate the study period was generally drier than the long-term average. During the study period, only the months of January, March, and April were wetter than average. The average water table depth for the three-yr study period is indicated by the solid line in fig. 3. The ranges in water table depths observed are indicated by the vertical lines.

Considerable variation occurred among measurements of water table depths and precipitation taken during the same time period in different years of observation. The variation was particularly significant for the Glynwood soils. Considerably different conclusions could be drawn if only the driest or the wettest observations were used to characterize the depth to the water table in the Glynwood soil.

Comparisons of the curves shown in fig. 3 indicate a water table was observed within a depth of 165 cm in the Hoytville taxadjunct between the last two wk of February and the end of June and within a depth of 165 cm in the Glynwood from early March to the end of June. The highest average water table level was within 20 cm of the soil surface during April and the first two wk of May in the Hoytville soil but was never at a shallower depth than 30 cm in the Glynwood. In addition, the minimum depth to the average water table in the Glynwood soil occurred two wk earlier (early April) than the Hoytville soil (fig. 3, well Type A). The months of January, parts of February and June, and July through December are not shown because water was not observed in the observation wells during these periods. The fall of the water tables in May generally corresponded to the onset of leaf formation.

TABLE 2

Comparison of long-term and study period average precipitation values.

Month	26-yr* Avg.	3-yr** Study
	mm	
Jan.	45	54
Feb.	37	29
Mar.	62	102
Apr.	80	106
May	85	54
June	98	90
July	101	94
Aug.	80	51
Sept.	76	50
Oct.	47	14
Nov.	67	37
Dec.	58	46
Total	836	727

*Measured at the Northwest Branch of the Ohio Agricultural Research and Development Center
**Measured at the study site

SOIL MORPHOLOGY VERSUS WATER TABLE DEPTH. Soil structure can have a profound effect on hydraulic conductivity and water movement. Bouma and Anderson (1973) found good agreement between estimates of hydraulic conductivity, calculated from the width and length of voids between structural units, and field-measured hydraulic conductivity. The dominant structure in the subsoil of both soils was prismatic or subangular blocky, and both contained many vertically continuous conductive pores that probably did not severely restrict water movement (table 1). The C3 horizon of the Glynwood, however, was platy and did not have many vertically continuous pores. Water movement through the platy horizons at a depth of 119 cm was probably much slower than through the shallower prismatic horizons and may account for the difference in water table levels between pipes observed in the Glynwood soil. Similar results have been reported for moderately fine-textured soils in central Ohio (Zobeck and Ritchie 1984) and Indiana (Harlan and Franzmeier 1974).

In addition, the clay content in the B horizon was slightly higher in the Glynwood than in the Hoytville taxadjunct (table 1). The difference was not large and probably did not significantly affect water movement in this zone. This view is supported by measurements of bulk density in this zone which were essentially the same for both soils, varying from 1.4 to 1.6 g/cm^3.

Soil color features are considered visual evidence of the effects water table regimes have had on the oxidation, reduction and translocation of free oxides, primarily of iron (Simonson and Boersma 1972). *Soil Taxonomy* (Soil Survey Staff 1975) suggests that horizons with mottles that have chroma of two or less and value, moist, of four or more (low chroma mottles) are saturated with water at some period of the year that the temperature of the horizon is above 5°C if the soil is not artificially drained. The amount of time the soil is saturated is not specified.

The soil color features were described in detail for each soil and are listed in table 1. The subsoil of the very poorly drained Hoytville taxadjunct was dominated by low chroma colors. These colors suggest prolonged saturation at relatively shallow depths. Water tables were observed within 30 cm of the soil surface for an average of 1.5 months and within 100 cm for an average of 3 mo during the spring in the Hoytville taxadjunct (fig. 3). Low chroma colors occur only as surface coatings in the Glynwood soil. The coatings occurred in the Btl horizon at a depth of 20-33 cm (table 1). This depth range corresponds to the highest average perched water table depth although considerable variation in the data was observed. Water tables were observed within 30 cm of the soil surface for an average of less than two wk in the Glynwood. The amount of time the entire profile was saturated is unknown because unsaturated zones may have occurred below the water table indicated by well Type A as previously noted. More Type B wells or tensiometers installed at different depths would be needed to draw further conclusions. These results suggest that soils developed from similar materials may appear dominantly gray when saturated for as little as an average of 1.5 mo and have gray coats on ped surfaces when saturated for as little as two wk each year, on the average. These results are particularly significant because they are based, in part, on data from particularly wet months, March and April, compared to long-term average precipitation values.

Differences in soil colors attributed to the duration of saturation are caused by oxidation and reduction reactions produced by microbial activity. Gray colors in soils are generally attributed to reducing conditions (low Eh potential). The reduced conditions occur in saturated soils when O_2 is metabolized by soil microbes and lost (Alexander 1977). In addition, since microbiological activity increases with progressively warmer conditions (Alexander 1977), the soil solution is more rapidly reduced at higher temperatures. The Hoytville taxadjunct was saturated to within 40 cm of the surface throughout April and May. During these months the soil temperature at a depth of 10 cm, as measured under a sod crop at the Northwest Branch, averaged 8.5 °C and ranged from 6.8 to 10.2 °C in April and averaged 14.4 °C and ranged from 12.6 to 16.3 °C in May. The Glynwood soil was saturated to within 40 cm of the surface earlier in the year, through late March and early April when the soil temperatures were cooler. The soil temperature at the Northwest Branch at a depth of 10 cm averaged 2.3 °C and ranged from 1.4 to 3.2 °C in March. Although measurements of soil temperature were not taken at the study site, the saturated forest soils probably had even lower temperatures than measured under the sod crop. The soil matrix of the Hoytville taxadjunct was almost uniformly gray throughout the upper 40 cm while only gray coatings on ped surfaces were observed in the Glynwood. These color differences may be due to redox potential differences associated with temperature related microbial activity. At the lower temperatures of March and April, microbial activity would be reduced and the soil solution would retain oxygen longer and remain at a higher oxidation state than at higher temperatures later in the spring. In the early spring the redox potential may not remain at a low level long enough to induce changes in soil color that occur readily at lower potentials reached later in the season. This analysis suggests longer periods of saturation may be needed to attain the same color characteristics in soils that are saturated during cooler months. Additional study of the redox potentials of the soil solutions are needed to verify this hypothesis.

CONCLUSIONS

Water tables were observed within 165 cm of the surface between the last two wk of February and the end of June in the very poorly drained Hoytville taxadjunct. The water tables observed in the moderately well drained Glynwood soil occurred from early March to the end of June. The highest water table was observed at a depth of 10 cm during the last two wk of April in the Hoytville taxadjunct and at a depth of 30 cm during the first two wk of April in the Glynwood. Observations of water table depths and precipitation varied considerably for the same time periods over the three-yr study.

The water regimes of each soil were correlated with soil color features. The Hoytville soil was dominantly gray throughout the subsoil. The Glynwood soil had gray coatings on ped surfaces. The gray soil matrix of the Hoytville taxadjunct formed in horizons where water tables were observed for as little as 1.5 mo. Gray coatings were observed in the Glynwood soil in horizons where water tables were observed for only two wk. Further research is needed to relate water table depth, duration and redox potential to soil color features.

ACKNOWLEDGMENTS. Salaries and research support provided by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Journal Article No. 34-84.

LITERATURE CITED

Alexander, M. 1977 Introduction to soil microbiology. 2nd ed. John Wiley and Sons., New York, NY. 467 p.

Baker, F. J., G. M. Schafer and N. Holowaychuk 1960 Surficial materials and soils of Paulding County, Ohio. Ohio J. Sci. 60: 365-377.

Blevins, R. L. and L. P. Wilding 1968 Hoytville soils: Their properties, distribution, management and use. Ohio Agr. Res. and Dev. Cen., Res. Bull. 1006. 30 p.

Bouma, J. and J. L. Anderson 1973 Relationships between soil structure characteristics and hydraulic conductivity. *In:* R. R. Bruce, (ed.), Field soil water regime. Amer. Soc. Agron. Spec. Pub. No. 5. Madison, WI. p.77-105.

Bullock, P., M. H. Millford and M. G. Cline 1974 Degradation of argillic horizons in Udalf soils of New York State. Soil Sci. Soc. Amer. Proc. 38: 621-628.

Duncan, N. A. 1979 The moisture regimes of six soil series of the central lowlands of Scotland. J. Soil Sci. 30: 215-223.

Franzmeier, D. P., J. E. Yahner, G. C. Steinhardt and H. R. Sinclair, Jr. 1983 Color patterns and water table levels in some Indiana soils. Soil Sci. Soc. Amer. J. 47: 1196-1202.

Fritton, D. D. and G. W. Olson 1972 Depth to the apparent water table in 17 New York soils from 1963 to 1970. New York's Food and Life Sci. Bull. No. 13. 39 p.

Gordon, R. B. 1969 The natural vegetation of Ohio in pioneer days. Ohio Biol. Surv. New Series Bull. Vol. 3, no. 2.

Harlan, P. W. and D. P. Franzmeier 1974 Soil-water regimes in Brookston and Crosby soils. Soil Sci. Soc. Amer. Proc. 38: 638-643.

Innes, R. P. and D. J. Pluth 1970 Thin section preparation using an epoxy impregnation for petrographic and electron microprobe analysis. Soil Sci. Soc. Amer. Proc. 34: 483-485.

Rapparlie, D. F. and D. R. Urban 1973 Soil survey of Hancock County, Ohio. Soil Conserv. Serv. U.S.D.A. U.S. Govt. Printing Off., Washington, DC.

Schelling, J. 1960 New aspects of soil classification with particular reference to reclaimed hydromorphic soils. Intern. Congr. Soil Sci. Trans. 7th Madison, WI. 4: 218-224.

Simonson, G. H. and L. Boersma 1972 Soil morphology and water table relations: II. Correlation between annual water table fluctuations

and profile features. Soil Sci. Soc. Amer. Proc. 36: 649-653.
Smeck, N. E., A. Ritchie, L. P. Wilding and L. R. Drees 1981 Clay accumulation in sola of poorly drained soils of western Ohio. Soil Sci. Soc. Amer. J. 45: 95-102.
Soil Survey Staff 1951 Soil survey manual. U.S.D.A. Handb. No. 18. U.S. Govt. Printing Off., Washington, DC. 503 p.
Soil Survey Staff 1972 Soil survey laboratory methods and procedures for collecting soil samples. Soil Conserv. Serv. U.S.D.A., U.S. Govt. Printing Off., Washington, DC. 63 p.
Soil Survey Staff 1975 Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Soil Conserv. Serv. U.S.D.A. U.S. Govt. Printing Off., Washington, DC. 754 p.
Soil Survey Staff 1980 National soils handbook Ch. 5 p. 6. N.S.H. Notice 63. Soil Conserv. Serv., U.S.D.A. Washington, DC.
Soil Survey Staff 1981 Soil survey manual. Ch. 4. Examination and description of soils in the field. Issue 1, Directive 430-V-SSM, May, 1981. Soil Conservation Service, U.S.D.A., Washington, DC.
Taylor, G. S., T. Goins and N. Holowaychuk 1961 Drainage characteristics of Toledo and Hoytville soils. Ohio Agr. Exp. Sta. Res. Bull. 876. 23 p.
Thorp, J. and E. E. Gamble 1972 Annual fluctuations of water levels in soils of the Miami catena Wayne County, Indiana. Sci. Bull. No. 5., Earlham Coll., Richmond, IN. 25 p.
Zobeck, T. M. and A. Ritchie, Jr. 1984 Analysis of long-term water table depth records from a hydrosequence of soils in central Ohio. Soil Sci. Soc. Amer. J. 48: 119-125.